A System to Quantify Upper Limb Function

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Abstract

Hand dysfunction presents patients with many challenges in performing activities of daily life. In order to restore manipulative functionality, patients participate in rehabilitation therapy programs. However evaluation of treatment, particularly for children, is often limited to subjective assessments and qualitative measures. This project involves the instrumentation of a child's toy with a pressure sensor, in order to obtain quantitative grip strength measurements. This data is collected and is wirelessly communicated to a laptop computer. Through a virtual instrument analysis system implemented on a laptop with Labview, the collected data is recorded, analyzed and displayed. The theory and design of the grip strength instrumentation and data acquisition, and the main structure of the virtual instrument analysis system for this project is presented. This overall system allows for the quantitative assessment and monitoring of muscle function in the hand, and can help to evaluate the effectiveness of rehabilitation treatment. In the future, this technology can also be retrofitted towards other toys in order to target a wider range of age groups for children.

Key words: Grip strength, hand rehabilitation therapy, quantitative hand functionality, instrumentation

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CHAPTER 1
INTRODUCTION

1.1 Background

Hand dysfunction can arise due to numerous situations including trauma, neurological impairment, and brachial plexus injuries. However, manipulative abilities of the hand are crucial in performing numerous activities of daily life. Hand impairment significantly reduces the quality of life of a person, presenting many inconveniences, obstacles and challenges. Therefore, patients often participate in rehabilitation and therapy programs in order to restore hand functionality and resume normal lifestyles.

A major limitation of rehabilitation programs is the use of qualitative or semi-quantitative measures for hand function evaluation [1]. Variations in many current clinical practices exist since these methods are based on subjective assessments of therapists with ranging degrees of experience [2]. While there are some commercial devices available for quantitative measurements, many of these devices do not communicate with the computer to allow for subsequent analysis and computerized tracking [3]. They are also limited to one type of measurement instead of having multifunctional purposes. Furthermore, the devices currently available are designed for adult use, and quantitative measurement devices targeting children have yet to be developed. This limitation is particularly challenging for the assessment of rehabilitation for children suffering from peripheral nerve damage. Thus, an accurate quantitative assessment and monitoring tool is required in order to validate the outcome of rehabilitation treatment and quantify the effectiveness of therapy.

1.2 Objectives

The objective of this project is to design a system which will quantitatively measure and assess muscle function in the upper extremity during therapy and rehabilitation. This system will target hand functional assessment of children, through the instrumentation of a child's toy with the necessary sensors and electronics. The instrumented toy will be able to obtain both measurements for grip strength and range of motion (tilt angle during pronation and supination of the forearm).

Furthermore, through the design of a software program and the transmission of data, physiotherapists will be able to efficiently view and analyze the quantitative information on a computer. In addition to being able to view real-time acquired data, they will be able to store data for analysis at a later time, and thus maintain a full record to track a patient's progress during therapy (for both grip strength and range of motion measurements).

1.3 General Approach

A children's rubber squeeze toy will be used in order to obtain pneumatic data for grip strength measurements. The selected toy will be fitted with a pressure sensor and a three-axis accelerometer to measure the child's grip force and range of motion respectively. The data acquired using these sensors will then be wirelessly transmitted through the use of RF transmission to a microcontroller, and then read into the software program on the laptop.

The software for this project is designed using Labview, with a user-friendly graphical interface. An organized file storage system will be implemented to allow for organized record keeping for the physiotherapists. They will be able to choose the type of measurements they would like to acquire (range of motion or grip strength) and whether they would like to acquire new data or view and analyze previous sessions. Whenever new data is acquired, it is saved to a text file with the other data from the patient.

1.4 Scope of Project

This project involves the modification of a child's toy with instrumentation to obtain both grip strength and range of motion measurements. The data will be wirelessly communicated to a microcontroller and into a virtual instrument analysis system implemented on a laptop computer with Labview. This program will acquire, process, analyze and store records of the physiological data in addition to providing interactive displays.

Larissa Schudlo and Natalie Tong (Group 18) have worked jointly to accomplish these objectives for the design of the instrumentation system to quantify upper limb function. This is the portion of Group 18 working on the design of the instrumentation to quantitatively measure grip strength, design of the common graphical user interface and patient file storage for both the range of motion and grip strength tests, and the design of the analysis, processing and storage software for the grip strength data. Larissa Schudlo is responsible for the design of the toy to measure range of motion, the wireless communication for data acquisition to the laptop, and the software for analyzing, processing and storing the range of motion data.

CHAPTER 2

LITERATURE REVIEW

In order to assess hand functionality, many different motions have been investigated. Common tests include grip strength, lateral prehension pinch strength, pronation and supination, and external rotation of the upper extremity. While there are various devices commercially available such as dynamometers to measure grip strength (i.e. JAMAR and NK dynamometers), many of these devices are unable to directly record and analyze data through the computer [3]. Furthermore, these devices are designed for adult use. Evident in Figure 2.1, a child with hand dysfunction will likely not be able to grasp this object and thus accurate measurements will not be able to be obtained. Moreover, it is clear that this device does not communicate the acquired data to a computer. Instead, there is a dial located at the top to allow the physiotherapist to see the measurement recording and manually record this value.

Figure 2.1: Jamar dynamometer [4]

Many studies have investigated the development of equipment to assess hand functionality, usually for a specific type of target patient and often designed to imitate common activities of daily life, for example use of a fork [5, 6, 7]. However there are both advantages and disadvantages of this approach. It is beneficial to imitate common activities since these are the daily tasks that a person will be performing while leading a normal lifestyle. Having direct measurements for these specific motions will help the patients readjust to normal life during and after their therapy, since they are performing these tasks. Conversely though, humans are very mobile creatures and thus there are an exceptionally large number of physical movements that the human body can perform. It is thus impossible to fully quantify all of these motions and design them all into functional assessment exercises. These common activities are also often fairly complex movements, in the sense that they require more than one simple movement. For example, moving a fork towards your mouth can require shoulder movement to lift the arm, external rotation about the elbow to bring the fork close to the mouth, supination to angle the fork in the correct orientation, and finally pinch strength to hold the fork in place. Due to this complexity, it is more challenging to effectively localize and target the specific movements that require rehabilitation. While the ability to measure multiple motions with one device is desirable, it is useful to be able to distinctly distinguish between the quantitative measurements for each specific motion, so that the most appropriate treatments can be designed for optimal improvement.

Some past groups have also developed computerized systems to quantitatively evaluate hand functionality, store patient data, and provide stimulating virtual-reality therapy sessions [3, 6, 8, 9]. Studies by C.-H. Yang *et al*. [3,8] have successfully used a pneumatic squeeze dynamometer to assess a user's grip strength. This quantitative information was then communicated with a computer interface. Only this one type of functional assessment was quantified and communicated to the computer though – additional measurements were not obtained.

While Yang *et al*'s pneumatic squeeze dynamometer was successful, devices to quantitatively measure hand functionality in children have yet to be developed. In [10], adult equipment was used to measure outcomes of injuries in children. The hand size of a child is typically much smaller than a full grown adult, therefore it is more difficult for them to grasp these devices designed for adults. As a result, the measurements obtained may not accurately reflect the functional assessment of the child. Furthermore, these devices must be appealing to children to encourage them to use it, particularly for young infants and toddlers. A challenge in rehabilitation therapy for young children is to have them actually perform the required task. Thus, a child-friendly device (such as a toy) better targets this age range and can distinctly improve the effectiveness of rehabilitation treatment. The development of a device to specifically assess a child's grip strength and pronation/supination angle and velocity will allow for improved accuracy of evaluation and subsequently more effective treatment.

CHAPTER 3
STATEMENT OF PROBLEM AND METHODOLOGY OF SOLUTION

3.1 Problem Statement

Currently, assessment of rehabilitation therapy programs is very qualitative in nature. Furthermore, the limited quantitative measurement devices often do not communicate with the computer to digitally store information. These devices are also designed for adult use. Thus a quantitative measurement system that targets use by children must be designed, which obtains quantitative functional data and transfers this information through wireless communication for analysis and storage on a computer. For this project, functional assessment for grip strength and range of motion for pronation and supination of the forearm is targeted. Specifically for this portion of the project, grip strength assessment is focused on.

3.2 Methodology of Solution

The block diagram outlining the methodology of the solution to this design project is shown in Figure 3.1. In order to acquire grip strength measurements, a pressure sensor sealed to a child's squeeze toy is used. Not only must the toy be made of soft rubber so that it can obtain pressure measurements, but it must be small enough for a child to play with it and grasp it. Furthermore it must be bright and visually appealing for children.

Grip strength is can be measured as a force, however in this case it is measured as a pressure in units of mmHg. The amount of force that a child exerts by squeezing the toy is directly proportional to the pressure within the sealed toy. Since the pressure sensor is sealed to the toy, squeezing it will cause more air from within the toy to enter the pressure sensor, resulting in a higher pressure. The voltage output from the pressure sensor is then amplified.

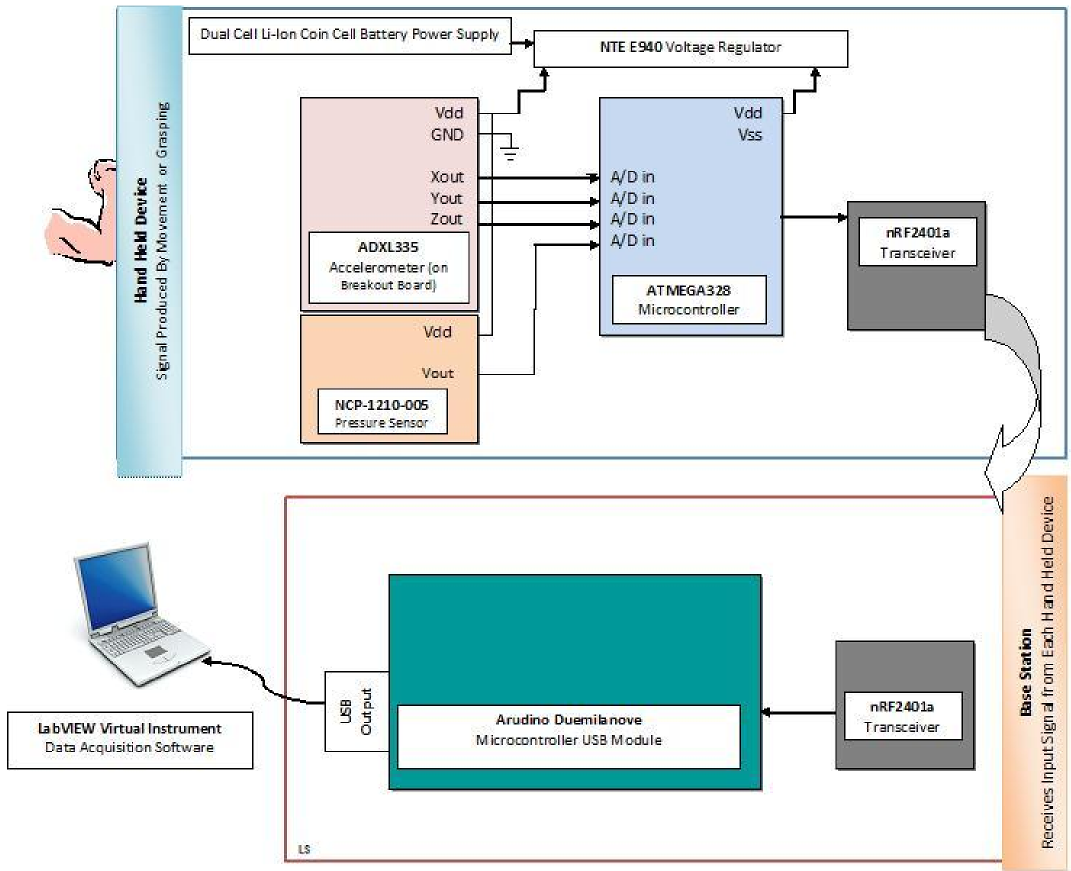


Figure 3.1: Block diagram of design methodology

The amplified pressure voltage, as well as data acquired from the three axis accelerometer used to obtain range of motion measurements, is then sent to a microcontroller and wirelessly transmitted to the Arduino Microcontroller/USB module via RF transceivers. The data is then read into the computer from this base station via USB, where it converted to a useful form (i.e. from output of microcontroller back to a voltage and then converted to pressure in mmHg) and visually displayed through a Labview software program. The acquired data is also stored on the computer, allowing for analysis at a later date and comparison with other data sets.

A common software program is designed to select between grip strength or range of motion measurement acquisition, and allows for an organized and efficient manner of patient file storage.

As outlined in Section *1.4 Scope of Project*, this component of the project encompasses the design of the grip strength acquisition hardware, as well as the subsequent analysis code and common interface code between grip strength and range of motion analyses. The design of the microcontrollers, wireless communication and base station for data transmission to the computer will not be discussed in this report.

CHAPTER 4

EXPERIMENTAL AND DESIGN PROCEDURES

The design for the instrumentation and hardware portion of the project can be divided into 4 main sections. Quantitative data is obtained by the pressure sensor when the toy is squeezed. This output data is amplified, then wirelessly transmitted to a microcontroller at a base station which connects to the laptop via USB for analysis. The block diagram for the instrumentation hardware implemented on the toy is shown in Figure 4.1 and the completed hardware instrumentation is shown in Figure 4.2. The user then accesses the common graphical interface of the designed software program. Within the program, they can select either grip strength or range of motion analysis, and the corresponding software is run. This portion of Group 18's project involves the data acquisition by the pressure transducer in the toy and amplification of the output signal, along with the software design for the common interface and grip strength analysis. Larissa Schudlo is responsible for programming the microcontroller and designing the wireless transmission of data, as well as the design of the range of motion analysis software.

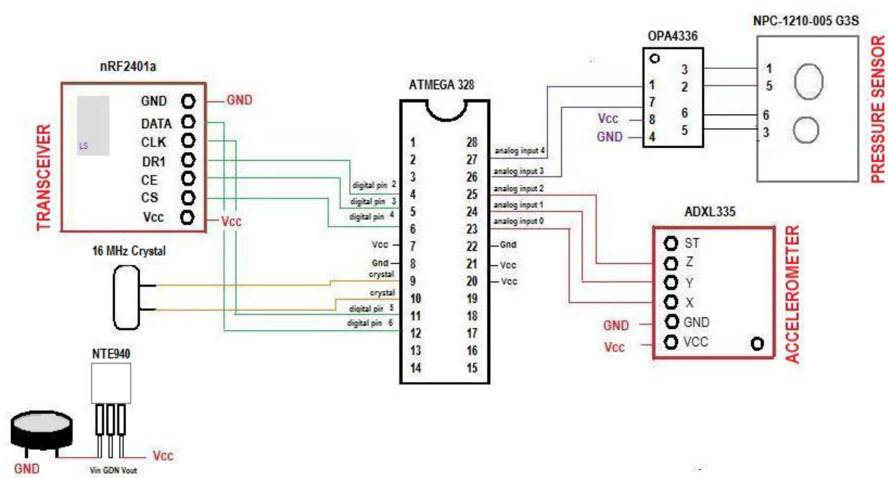
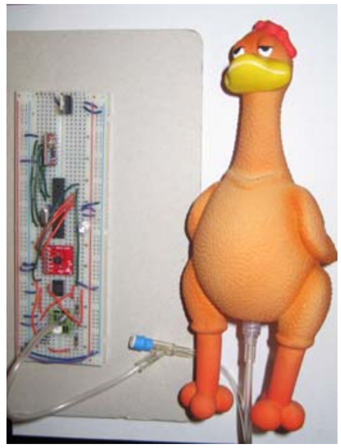
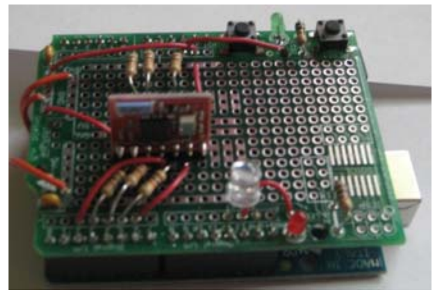


Figure 4.1: Block diagram of the electronics implemented on the child's toy. The quantitative data comes from either the pressure sensor or the accelerometer, and is wirelessly communicated to the base station via the transceiver.





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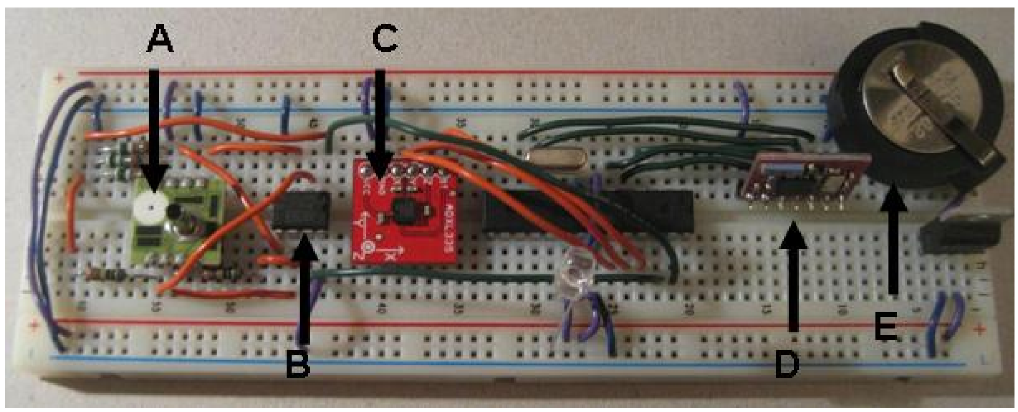


(iii)

Figure 4.2: Hardware setup for instrumentation system (i) Rubber chicken instrumented with sensors and electronics for wireless communication to (ii) the base station, which connects to a laptop computer via USB (iii) Complete instrumentation hardware implementation for the handheld toy. (A) Pressure sensor to be inserted into/connected to the toy. (B) Operation amplifier used to amplify output voltage from the pressure sensor. (C) 3-axis accelerometer for range of motion measurements (D) Transceiver for wireless communication of data. (E) 3.3V battery source

4.1 Selection of Child's Toy

In order to gain a comprehensive understanding of application for this project, physiotherapists from the MacHAND program were consulted, and the rehabilitation clinic in McMaster University's Children's Hospital was visited. It was observed and noted from the clinical visit that the young children preferred the use of brightly coloured objects that were small enough for their hands to grasp. Often these toys had different textures as well. Based on engineering requirements, the toy must be a soft, rubber squeeze toy with a whistle, so that the pressure sensor could be inserted and sealed to the toy for data acquisition.

The toy selected to meet these specifications was a squeezable rubber chicken as shown in Figure 4.2 (i). It was made of soft rubber and had a whistle at the base between the legs, where the pressure sensor could be sealed. Most notably, this chicken had a long neck and round head with a rooster comb. The head and neck were small enough for a child to grasp their hand around and squeeze. After removal of some of the interior stuffing, the squeezing of the head and/or neck resulted in a significant amount of air pressure change which could be detected by the sensor. For older children/other patients with larger hands, they would be able to grab around the plump body of the chicken for larger force measurements. The chicken is in a standing position and is vertically symmetrical as well, which is more ideal for the tilt angle/range of motion measurements.

In addition, the selected rubber chicken is brightly coloured and visually appealing for children. The rooster comb on top of the head is highly appealing for children to play with due to the unique grooves and texture, similar to the popular Sophie the Giraffe toy used in the clinic.

4.2 Design of Electronics for Grip Strength Measurements

In order to measure grip strength, a sensor to measure pneumatic air pressure within the toy was used. As child squeezes the sealed toy, the sensor would detect changes in pneumatic air pressure within the toy. This change in pressure within the toy is proportional to a child's grip force. The stronger the grip force, the higher the pressure within the squeeze toy.

For this purpose, the NPC-1210-005G3S pressure sensor was selected (Figure 4.3). It is a linear pressure sensor which measures up to 5 psi, or equivalently about 260 mmHg, which is ample for the purposes of children undergoing hand rehabilitation. It is a gauge type sensor, comparing the inner pressure of the toy (from tube inserted and sealed within the toy) to the ambient pressure (measured from the white disc).

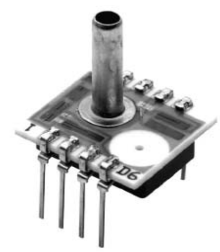


Figure 4.3: NPC-1210-005G3S Pressure Sensor

The differential voltage output from the pressure sensor, which is a wheatstone bridge, is then amplified following the circuit design of Figure 4.4. It is run by an input current which is typically 1.5mA, however as a safety net the circuit implemented was driven by a 1mA current (3.3V battery source running through 3x 10kΩ 1% resistors in parallel). A low power dual version operational amplifier (OPA2241 from Texas Instruments) was used according to Figure 4.4. The toy was then connected via tubing to the pressure sensor on the breadboard with instrumentation. The tube was sealed over both ends to prevent air leaks. A mercury manometer was then used to calibrate the linear sensor, to find both the offset voltage as well as the slope conversion for use in the software analysis. The output differential voltage is then wirelessly communicated to the microcontroller at the base station and read into the computer for software analysis. This remaining hardware component of the entire project was designed by Larissa Schudlo. The complete instrumentation set up is shown in Figure 4.2.

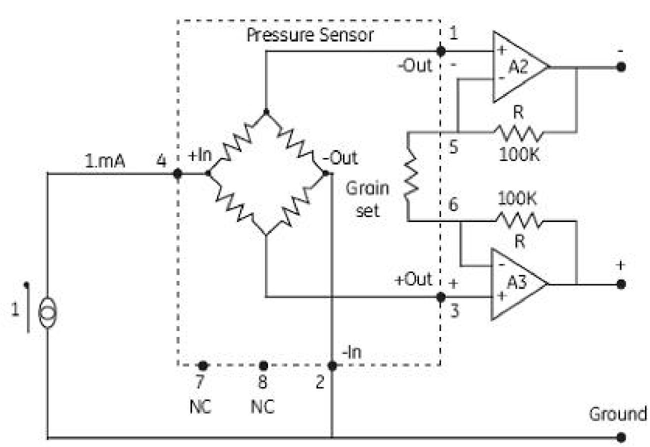


Figure 4.4: Pressure sensor amplification circuit

4.3 Design of Grip Strength Analysis Software

The software program designed has the graphical interface shown in Figure 4.5. It allows the user to either test the program or start the program, which both involve the real-time acquisition of pressure data. However, pressing the Start Program button allows for the data to be saved whereas pressing the Test Program button only allows for data acquisition without saving (i.e. to test that the program is working).

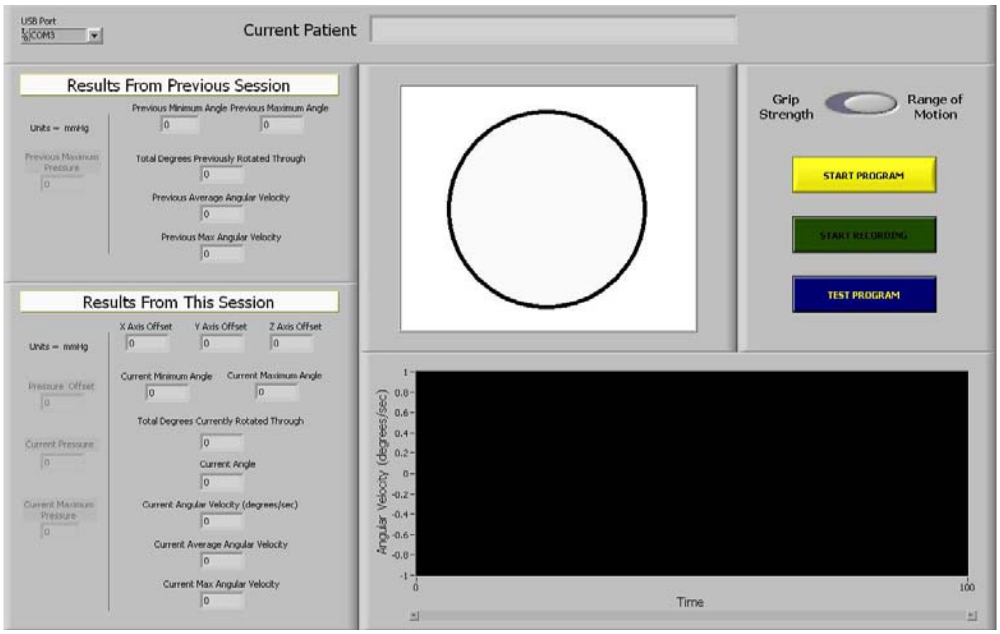


Figure 4.5: Front panel of software interface

Upon a value change of the Start Program button, all the appropriate displays are cleared and reset. The user then has the option to either record new data or view patient history. If the 'View Patient History' option is chosen, the user can select a file to open and be viewed on the waveform chart, along with the maximum pressure reading during that session. Upon selection of the 'Recording New Data' option, the user can choose to open a previous session to allow for comparison of results.

When the Start Measure button is pressed (or equivalently when testing the program), data acquisition begins. There are five channels read from the USB COM port, two of which correspond to the differential voltage from the pressure sensor. The input is calibrated upon the start of data acquisition, by acquiring ten samples of data and averaging it. This average is then converted to a pressure value, which corresponds to the pressure offset. Then, data is continually sampled and averaged for every five samples. The difference of these averaged samples is found and converted to pressure. The input value is converted to its corresponding voltage by multiplication by the 3.3V supply voltage and division by the 2^{10} bits from the microprocessor used. From the calibration of the pressure sensor with the mercury manometer, the linearity was found to be 0.04V/10mmHg. Thus the voltage is divided by this conversion (i.e. divided by 0.04V and multiplied by 10mmHg), and the offset during calibration is subtracted to find the acquired pressure. An error check is built into the program to ensure that a legitimate value is found (not a Not a Number).

The value of the pressure is continually written to a text file until the completion of the acquisition. Furthermore, the maximum pressure is stored in memory and continually updated on the front panel. Please refer to **Appendix A: Labview Code for Grip Strength Analysis** for the complete program code for the grip strength analysis software.

4.4 Design of Common Interface Software

The common interface software is designed to combine the grip strength and range of motion analysis codes, as well as allow for organized patient file storage and user-friendliness for the physiotherapist. Upon execution of the program, the displays are all cleared and enabled. Users are then prompted to create a new patient or select an existing patient. Creation of a new patient involves the creation of a new folder in the directory consisting of their first and last name, and their corresponding data files can be saved in this location. The other option is the selection of an existing patient, where the user opens the patient's folder, where all of their previous sessions have been stored. The current patient folder that is opened (indicating the patient's name) is listed on the front panel to avoid confusion as to which patient is being monitored.

Once the patient is selected, the user has the option to choose between grip strength or range of motion measurements and their selection is indicated on the front panel icon. Upon selection of the grip strength option, the appropriate displays on the front panel are enabled and cleared, whereas the range of motion displays are disabled, and the code for grip strength analysis is run. Similarly when the range of motion option is selected, the grip strength displays are disabled while the range of motion displays are enabled and cleared. The code for range of motion analysis is then executed. Once the appropriate analysis code is completed, the patient session is ended. The user then has the option to continue running the program (where they can once again select or create a patient) or exit the program. The software program continually loops through this sequence until exit program option is selected.

For the complete code for the common interface, please refer to **Appendix B: Labview Code for Common Interface**.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Pressure Sensor Testing and Calibration

The circuit shown in Figure 4.4 for a 1mA supply current was tested and calibrated using a mercury manometer. As expected, the pressure sensor exhibited linear voltage characteristics (it is a wheatstone bridge). From the graph shown in Figure 5.1, the slope was found to be about 0.04V/10mmHg. Thus, the voltage output from the sensor can be converted to a pressure value using this slope along with the offset voltage of approximately 0.2V. This offset is calibrated for through software analysis for when the chicken is not being squeezed and the internal pressure is 0mmHg.

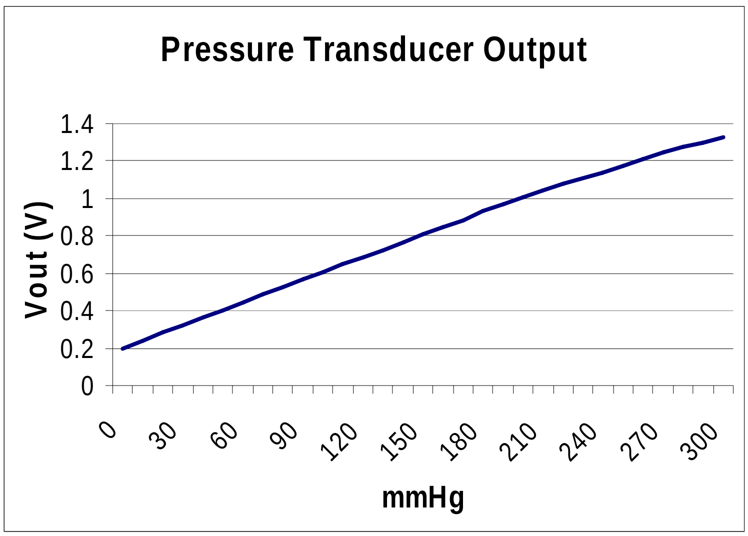


Figure 5.1: Pressure sensor calibration

Currently, the pressure sensor and related hardware is mounted on a breadboard and connected to the toy via a sealed piece of tubing. This is to allow for ease of testing. Ideally, if this project were to be marketed, all of the electronics would be smaller in size, soldered and incorporated directly on the squeeze toy. Furthermore, the technology for grip strength measurements can also be applied for another common rehabilitation assessment – pinch strength. Children can be asked to merely pinch the toy using their index finger and thumb, and subsequent pressure data can be obtained for this motion.

Upon discussion with physiotherapists, lateral pinch strength (between pinky finger and thumb) is another useful assessment although some modification may need to be made to account for these measurements. The output pressure/force will likely be much lower so a higher sensitivity of the pressure sensor may be required.

5.2 Software Interface and Results

Figures 5.2 and 5.3 show results for grip strength and range of motion measurements respectively (on software interface). The current patient is shown, along with the type of acquisition, data from a previous session, and the results from the current session. Based on the selection of the type of quantitative measurement, the appropriate displays are enabled and disabled. For example, as shown in Figure 5.2, the rotation graph and rotation results are greyed out.

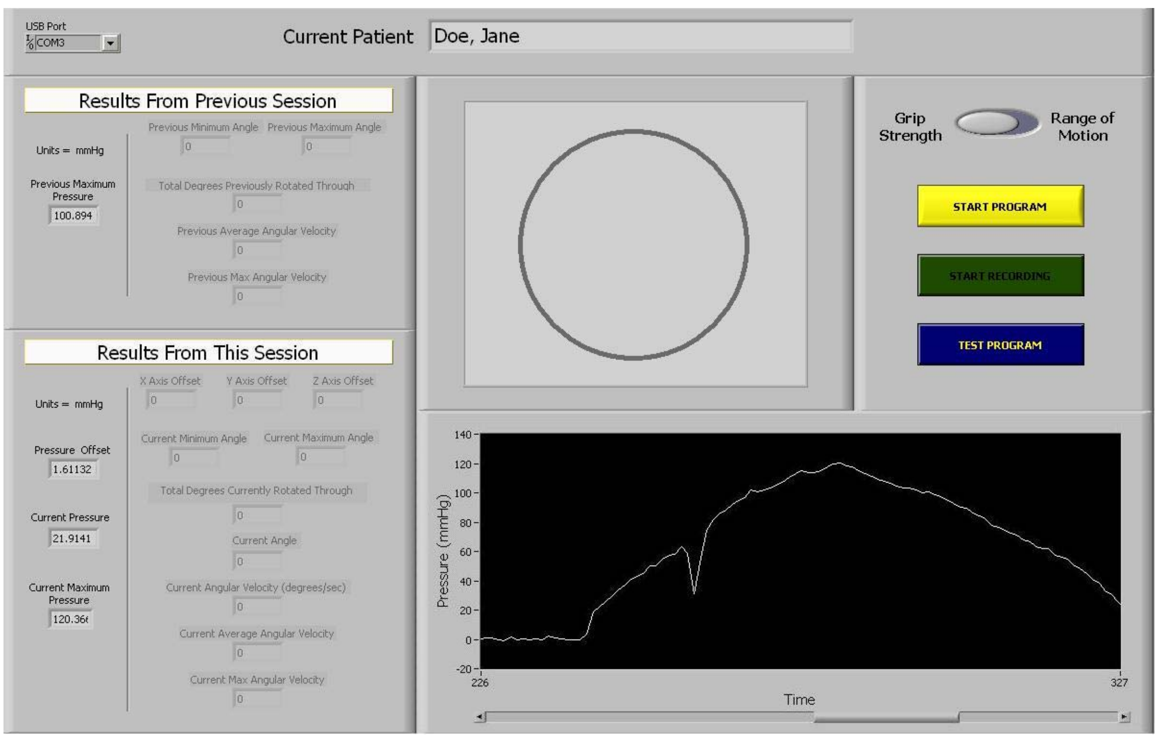


Figure 5.2: Grip strength test results

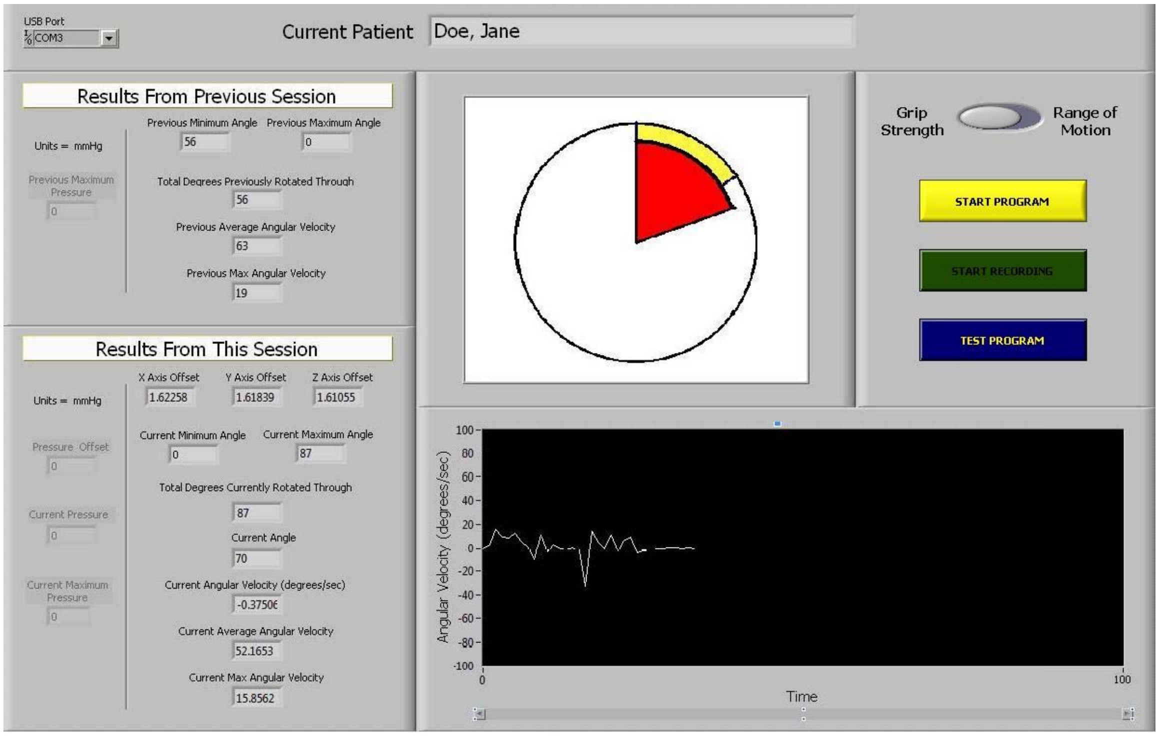


Figure 5.3: Range of motion test results

The grip strength data obtained in Figure 5.2 shows a fairly steady increase in pressure followed by a subsequent decrease as the toy is released. There is no set pattern to follow, as the code merely acquires the quantitative measurements on the pressure exerted on the toy. However this is useful for the physiotherapist to outline a defined program during acquisition, and gives them freedom for the type of data they wish to acquire. For example, they may ask the child to squeeze as hard as possible then slowly release to obtain their maximum strength, or they may ask them to squeeze the toy multiple times but at a high frequency. The software is able to track these chosen therapy session data. Furthermore, when previous data is compared to the current data being acquired, the same pattern can be followed for alignment of data and ease in comparison. As shown in Figure 5.3, it is clear to assess how a patient is performing to their previous session (red segment in the rotation circle shows a larger angle of rotation compared to the previous session indicated in yellow).

A useful feature of the program is the fact that the pressure data is written as a column of data in a text file. This allows the physiotherapist to perform additional post-processing with ease. Text files are easily opened in programs such as Microsoft Excel and Matlab, and the physiotherapists have more freedom since the data can be manipulated and analyzed as they please (without tying down the use of the computer with the Labview program for the actual data acquisition). With these quantitative measurements stored digitally, there is more flexibility for the physiotherapist to perform post-processing/analysis at another remote location. They are not limited to use the computer connected to the instrumentation system and the data is easily transferrable, thus increasing convenience and improving efficiency and workflow.

The design of the software program performs all the basic and necessary functions required. However additional code can always be added to increase the functionality of the program. As shown in Figure 5.2, there still may be some fluctuations in the pressure readings which are not fully accounted for. Further error checks to account for these fluctuations may be added. Error checks for the common code functionality may also be added (if the user, for example clicks a button when they should not have). Currently only simple error handlers have been used but more advanced implementations would significantly increase the robustness of the entire program. This is also true for the patient storage system implemented. Currently the code is under the assumption that the user is competent with computers and is fairly organized when it comes to file storage. However, to account for all types of users, it may be useful to enhance to code with stricter algorithms for file storage and organization. For example, a patient database can be created and the files automatically named according to the session number and date for storage. More advanced analysis tools (such as a running total of all the maximum pressures exerted) may also be included to further enhance the functional capability of the program.

Not only is this instrumented system and software program useful for physiotherapists in their assessment of rehabilitation therapy programs, but it also provides a basic framework for subsequent feedback to encourage patients during rehabilitation. The use of a visually appealing toy increases the appeal to children, since they can 'play' with the toy while undergoing rehabilitation sessions. In order to further encourage children to progress with their therapy, a future improvement would be the addition of biofeedback systems. For example, as the child squeezes the toy with more force, lights/sounds could go off or an interactive screen for the children can cause different events to occur. The children would have more fun during these sessions and be more willing to participate and practice their rehabilitation exercises so that they can see more stimuli from the biofeedback system with their improvements. With this form of encouragement, the children are more likely to improve at a faster rate during these rehabilitation programs.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The design and implementation of this instrumentation system allows for effective quantitative assessment of hand function for children. Through the use of a visually appealing toy, a child's grip force can be quantitatively measured based on the amount of pressure exerted when the toy is squeezed. With the user-friendly software program designed, physiotherapists can easily acquire and record both quantitative grip strength and range of motion measurements from the use of this one toy, instead of having multiple devices for various measurements. The acquisition of one measurement at a time allows for clarity in distinguishing between the measurements for each motion. Furthermore, an organized patient file storage system and comparison to historical data has been established, in order to allow for efficient tracking of patient progress.

This project has established a firm basis for the acquisition of quantitative measurements to assist in rehabilitation therapy monitoring. In addition, multiple types of quantitative measurements can be obtained through the use of this one system and toy, instead of requiring several devices for each individual function assessment. The next step would be to solder all the instrumentation sensors and electronics and encase them onto the toy itself. Additional analysis software can be programmed as well, for example to maintain a running log of maximum grip force. The software program is still at a basic level and can continually be added upon to increase the analysis power and functionality.

Grip strength and range of motion are just two of the basic functions of the hand that are monitored during rehabilitation. Quantitative measurements for additional movements such as lateral pinch strength and external rotation can further be implemented using similar technology and software analysis to that currently designed in this project. In addition, this concept and design may also be fitted towards other toys in order to target a wider variety of age groups for children. The implementation of a biofeedback system to incorporate instant feedback to encourage children during their therapy sessions is another potential future work.

Appendix A: Labview Code for Grip Strength Analysis

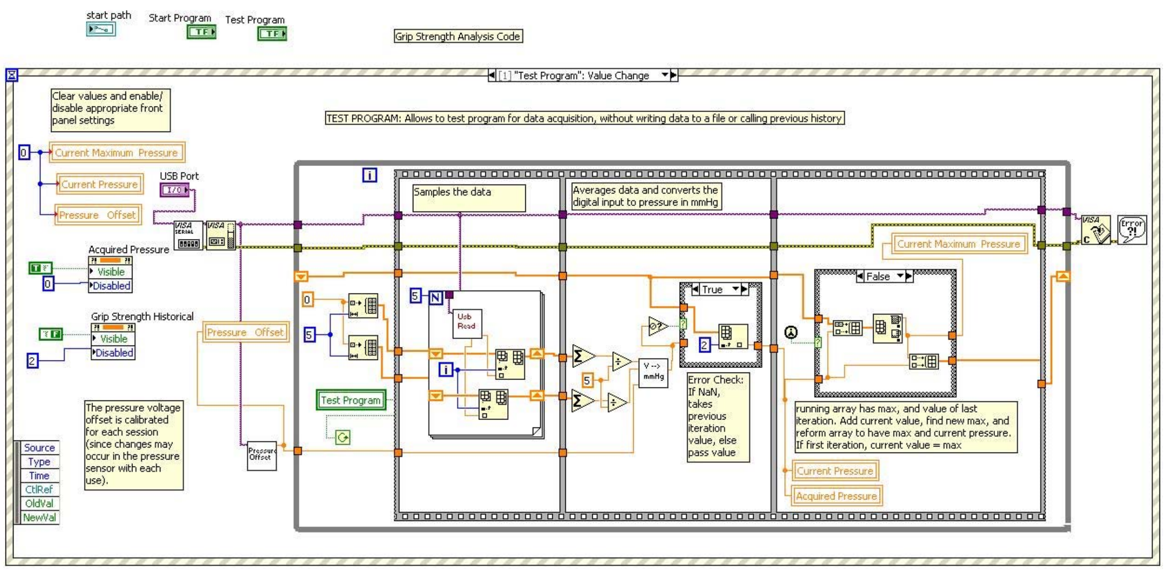


Figure A.1: Grip strength code – test program. When the Test Program button is pressed, this code is called. Real-time grip strength data is acquired and displayed on the waveform chart, along with the current maximum pressure, until the button is pressed again.

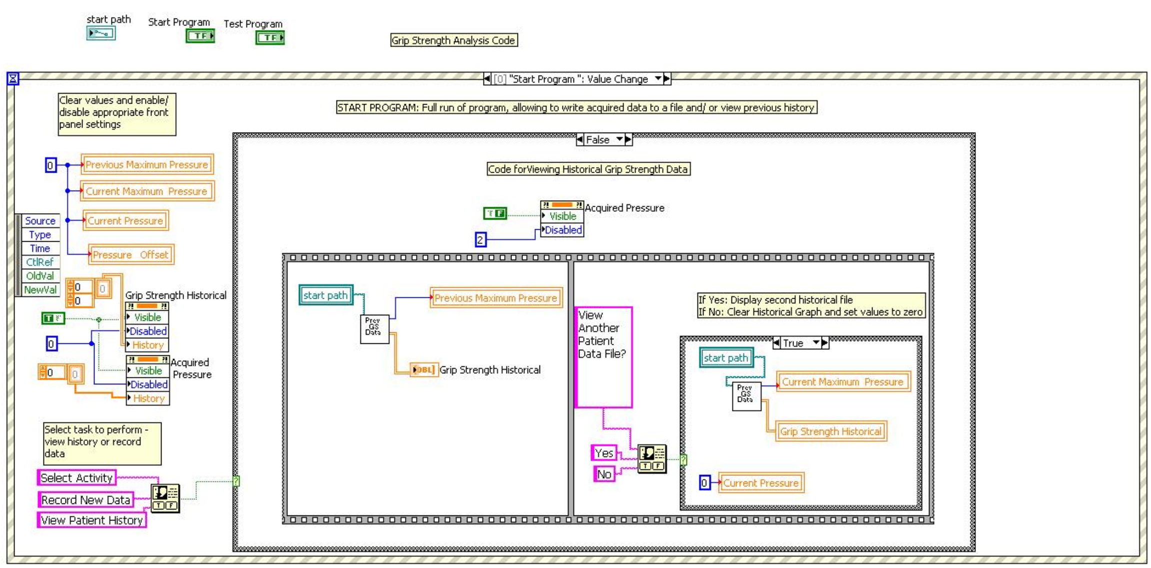


Figure A.2: Grip strength code – view historical data. When the Start Program button is pressed, and the 'View Patient History' option is selected, this code is called. The Prev GS Data subVI is called.

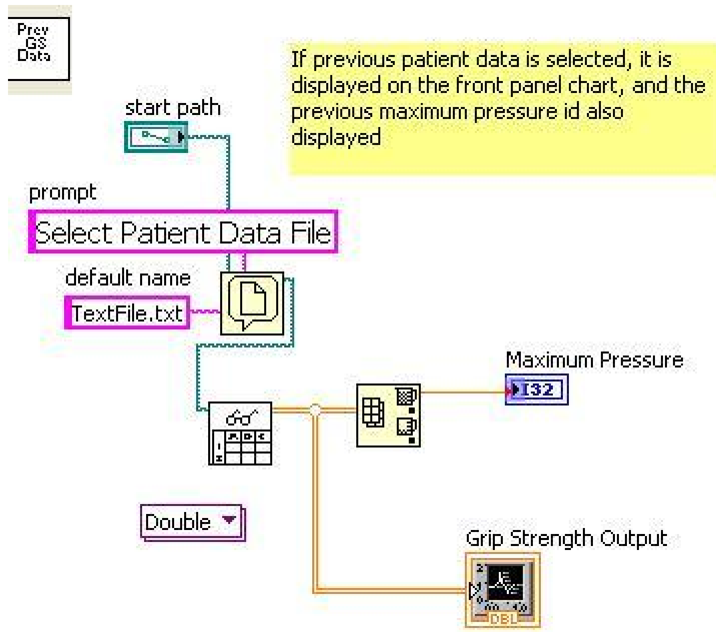


Figure A.3: Prev GS Data code. A patient data file is selected and displayed on the output waveform chart, along with the maximum pressure for that session.

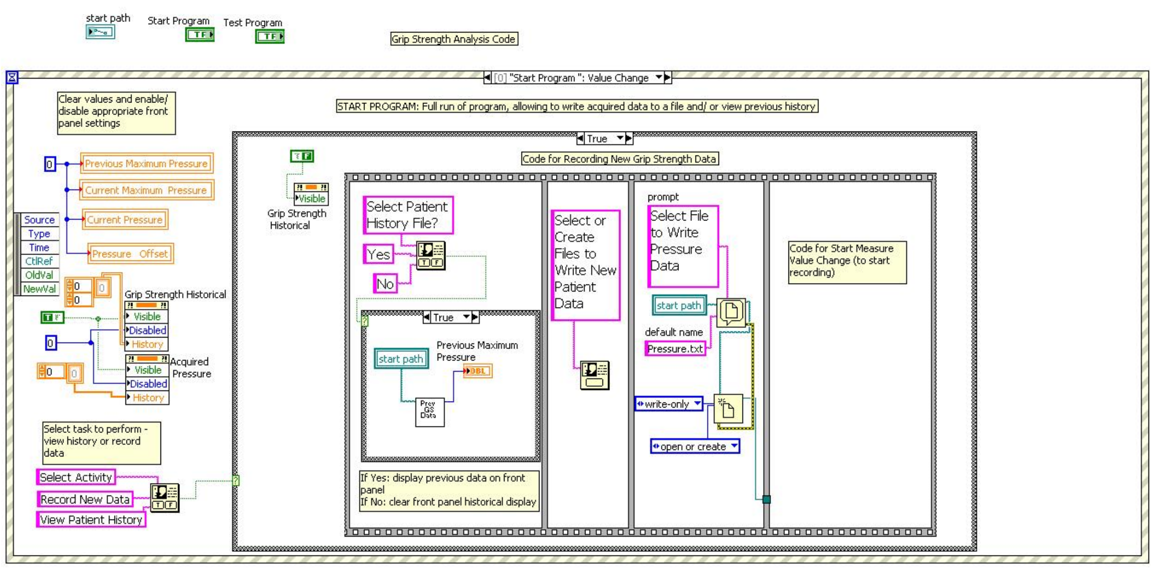


Figure A.4: Grip strength code – record data. When the Start Program button is pressed, and the 'Record New Data' option is selected, this code is called. The Prev GS Data subVI is called to allow for comparison of new data to a previous session. Once the Start Measure button is pressed the code in Figure A.5 is executed (in final sequence from within case structure).

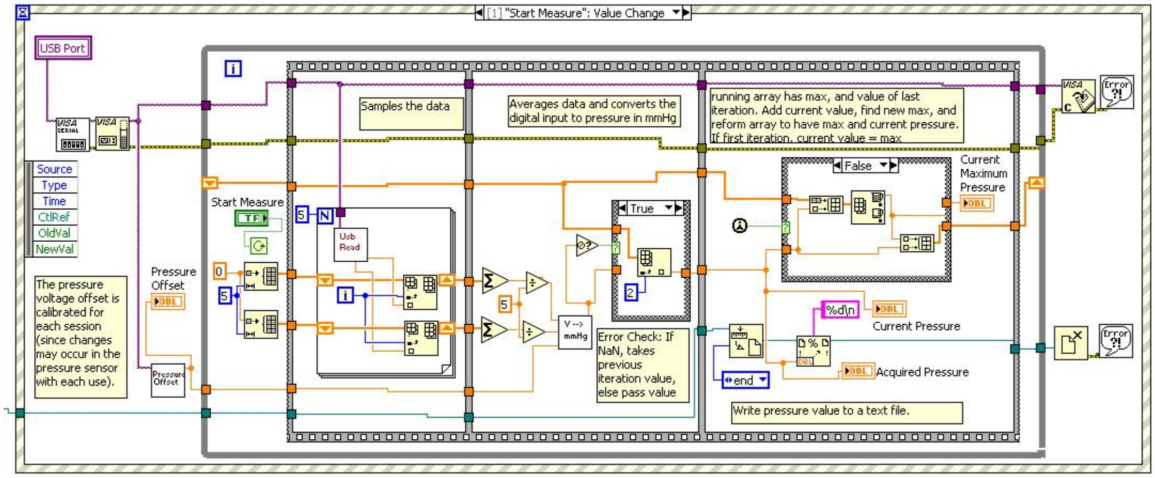


Figure A.5: Grip strength code – start measure. When the Start Measure button is pressed this code is executed. 5 data samples are read in and averaged then converted to a pressure reading. A running value of the current maximum pressure is maintained. All pressure values are written to a text file.

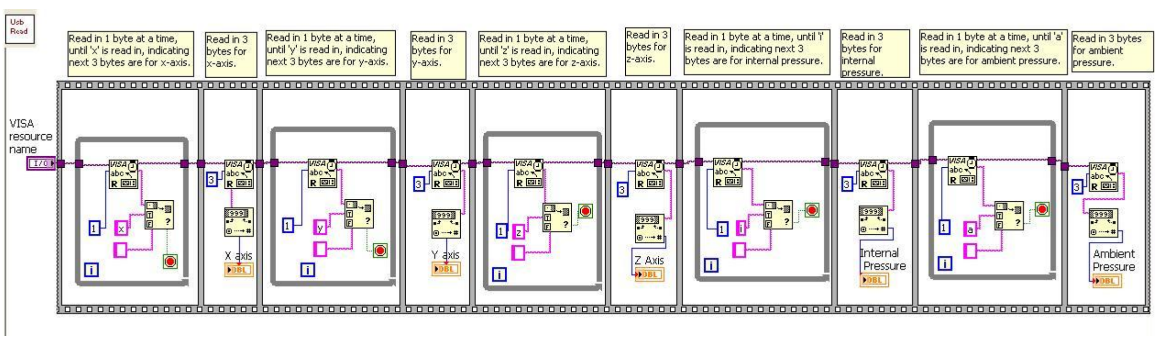


Figure A.6: USB read code. 5 channels of data are read from the USB COM port – one for each axis of the accelerometer and 2 for the differential pressure inputs.

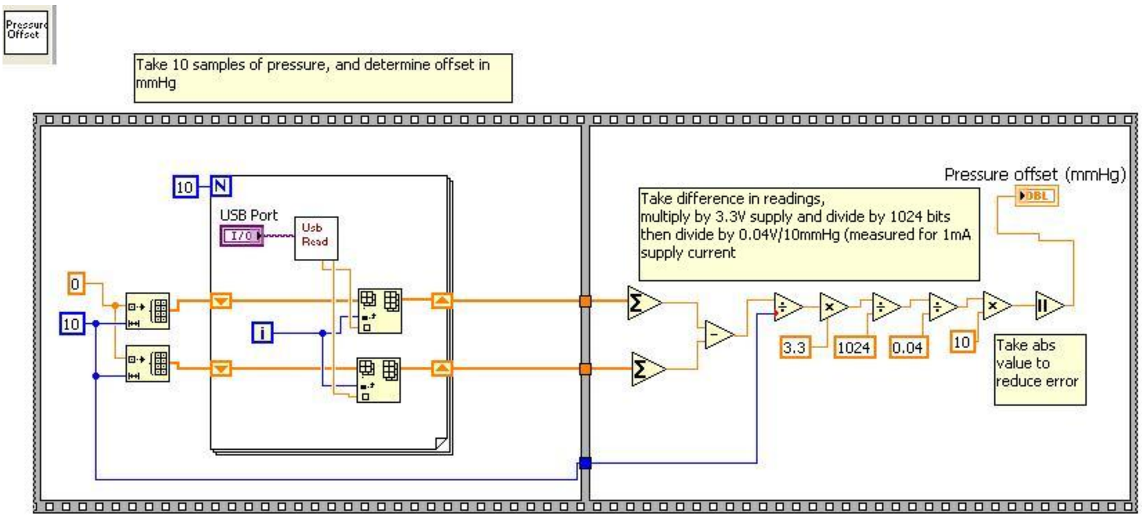


Figure A.7: Pressure calibration code. Ten samples of data are acquired and averaged then converted to pressure in units of mmHg. This code is called at the beginning of data acquisition to serve as an offset correction.

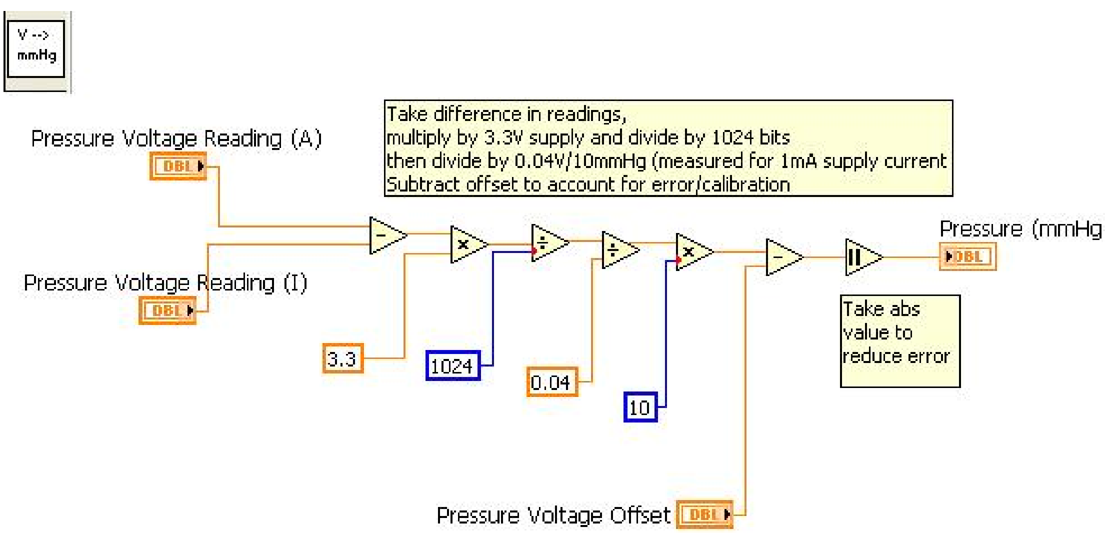


Figure A.8: Pressure conversion code. The difference between the differential voltage from the pressure sensor is found and converted to pressure in mmHg, subtracting the offset error found from calibration.

Appendix B: Labview Code for Common Interface

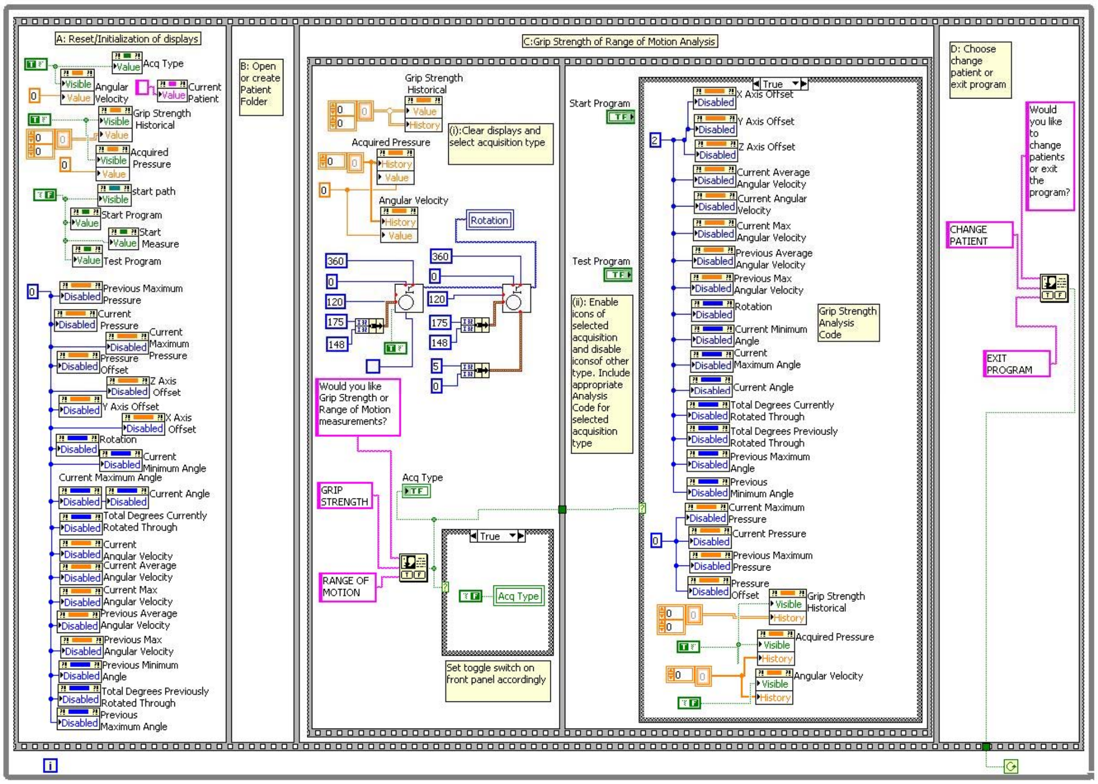
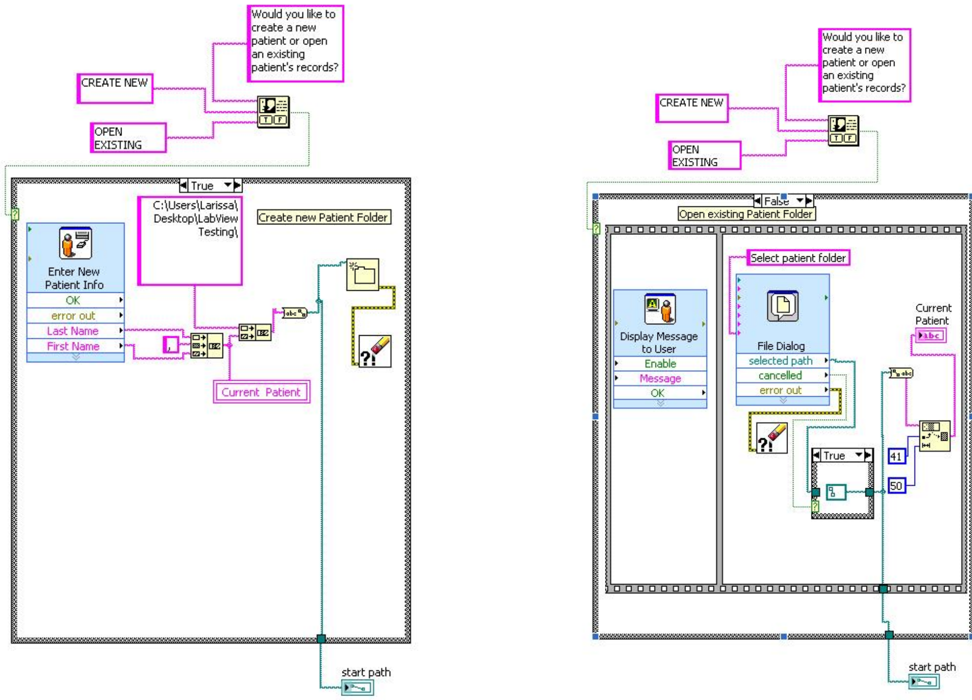


Figure B.1: Code for Common Interface. Frame A resets and initializes all displays. For code in Frame B, see Figure B2. Frame C determines the type of measurement acquisition. The grip strength code from Appendix A is inserted into the true case structure in C (ii). The range of motion analysis code is inserted into the false case structure. Frame D allows the patient to loop through the program again or exit.



(A) (B)

Figure B.2: Patient file code (A) Creates new patient folder (B) Opens existing patient folder

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